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Estimating the size of "buffer zones" for pig farm odours, and comparisons with an Australian Code of Practice

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1. Introduction

The Health Commission of Victoria produced in 1982 a Code of Practice for piggeries; it provides objective guidance on the minimum distances which should be allowed between new piggeries and various categories of adjacent residential areas, ranging from urban to isolated farmhouses. It also lays down guidelines for minimum distances of separation of slurry disposal areas from residential areas, roads and water supplies. The Code of Practice, or a modified version of it, might well find application in the United Kingdom also. However, although it gives objective guidance it is not clear whether the various rules which it contains are themselves derived objectively.

The Code distinguishes between fixed (size) and variable (size) "buffer zones" where the buffer zone defines the area around the piggery or disposal region within which the stated feature (residential area, road, etc) should not intrude. The fixed buffer zone is applied to the disposal of slurry or slurry treatment systems and the variable zone (whose size is adjusted according to herd size) when considering piggeries themselves. The distinction between the two types of zones is clearly arbitrary and requires some justification.

The present memorandum explores the various rules, contained in the Code of Practice, to which meteorological factors are likely to make important contributions.

2. Variable buffer zones

Table 1 summarises the Code of Practice values for four defined buffer zones in terrain without complicated topography or strongly-prevailing winds. It is seen

Table 1 Dimensions of variable buffer zones

Zone	Description	Distance (m)
1A	from PRP[a] to a statutory urban boundary	1.00 R[b]
1B	from PRP to a rural residential zone or area	0.75 R
2	from PRP to an isolated rural residence	0.25 R
3	from PRP to a famhouse (other than the property on the piggery)	0.20 R

Notes: (a) PRP is the "piggery reference point", usually the centroid of the piggery: if the piggery is very dispersed then the piggery perimeter is used to define the distance to the edge of the buffer zone.

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(b) R is the number of pigs (or 5 times the number of pigs over 70 days old on breeder units): R is set equal to 2000 for R values below 2000, and to 5000 for R values greater than 5000.

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that the linear dimension of the buffer zones is directly proportional to R (an adjusted herd size), a suspiciously-simple relation! The shortest zone distance is seen to be 0.2 x 2000 = 400m, sufficiently large to provide some justification for an initial appraisal of the zone criteria in terms of a point source of odour emission. Following the approach discussed by Thompson and D'Costa (1983), the ground-level concentration at the edge of the buffer zone, distance x from the source, is, for a ground level source,

$$C(x) = \frac{Q}{\pi U \sigma_{yI}(x)\, \sigma_z(x)} \exp\left(-y^2/2\sigma_{yI}(x)^2\right) \qquad (1)$$

where Q is the emission rate (units/s), $\sigma_{yI}(x)$ and $\sigma_z(x)$ the standard deviations of the lateral (acrosswind) and vertical distribution of the odour (the latter taken about an axis at ground level), y the crosswind distance of the receptor from the odour plume's axis and U the mean wind speed averaged over the vertical distribution of the odour. In practice the turbulent mixing in the pighouse wake results in non-zero initial values for σ_{yI} and σ_z : a first approximation is to assume that the effective initial source is distributed uniformly in the horizontal and vertical with dimensions Y and Z , where Y is the crosswind dimension of the house, and Z is between one and two times the vertical dimension. Thompson and D'Costa (1983) suggested that account could be taken of this initial mixing by defining a virtual source, equal in strength to the actual source, and placed a distance X upwind from the building so that a rough match between actual and virtual odour distribution would be found close to the building.

Values for X_z for different values of Z are given in Table 2; they are distinguished by the subscript z to indicate that they refer to vertical

Table 2 Distance X_z of virtual source from pig house

Stability category	Z=4m	6	8	10	12	16	20
A	25	35	45	55	70	85	110
B	30	45	60	75	90	125	160
C	40	60	85	105	130	180	220
D	55	80	115	140	175	250	330
E	90	140	200	265	330	450	590
F	160	265	400	540	700	1050	1450

mixing in the building wake. They are derived from estimates for $\sigma_z(x)$ (Table 3) based on values given by Hosker (1974).

A rational assessment of the likely size of the buffer zone is presumably to be based on a "worst case" analysis, with light winds, stable conditions, and plume blowing directly from source to receptor so that axial concentrations of odour

Table 3 Estimates for σ_z for a roughness length of 0.1m

$$\sigma_z = \frac{aX^b}{1+cX}$$ where X is in metres

Stability category	a	b	c
A	0.105	1.07	1.11×10^{-4}
B	0.125	0.96	0.73×10^{-4}
C	0.110	0.92	0.64×10^{-4}
D	0.095	0.89	0.80×10^{-4}
E	0.066	0.87	0.76×10^{-4}
F	0.062	0.78	0.60×10^{-4}

are experienced. Equation (1) then reduces to

$$C(x) = \frac{Q}{\pi U \sigma_{yI}(X_y+x)\,\sigma_z(X_z+x)} \qquad (2)$$

with X_y and X_z both zero if a point source is postulated. It is assumed that the odour offensiveness is determined by the odour concentration sampled nearly instantaneously, for which the values for σ_{yI} given in Table 4 are appropriate: they are based on estimates given by Smith and Hay (1961).

Table 4 Estimates for σ_{yI}

$$\sigma_{yI} = d\,x^e$$

stability category	d	e
A	0.080	1.0
B	0.060	
C	0.050	
D	0.040	
E	0.027	
F	0.017	

Table 5 gives estimates for axial odour concentrations at different distances downwind for a "worst-case" assumed to be characterised by a wind speed of 1 m/s and class F stability. The values refer to concentrations at ground level, but at the distances of importance in the present context ($\gtrsim$ 400 m), they will be good approximations for samples from near ground level up to head height of standing adults. The tabulations have been normalised to apply to an odour

Table 5. "Worst case" odour concentrations downwind from (a) a point source (b) a single pig house with the same odour emission and (c) a circular pig unit providing a uniform odour source

Distance downwind from source (m)	Odour concentrations for source of unit size		
	(a) point source	(b) single building source	(c) circular site
200	.025	.0037	.0014
300	.012	.0032	.0012
400	.0072	.0027	.0011
500	.0049	.0023	.00095
700	.0027	.0017	.00079
1000	.0015	.0011	.00063
1500	.00073	.00062	.00044
2000	.00045	.00040	.00033
3000	.00023	.00022	.00019
4000	.00015	.00014	.00013
5000	.00010	.00010	.000095
7000	.000061	.000060	.000058
10000	.000037	.000036	.000035

Note: in (c), distance is measured from centre of site which is 100m in diameter.

source of 1 unit s^{-1}, released either from a point, or from a single-house piggery 30 m broad (acrosswind) producing an initial source which is well-mixed across this breadth, and over a height of 6m: in the latter case the listed odour concentrations have been obtained by using a series of sub-sources of equal size placed uniformly across the piggery breadth: X_y (eg (2)) has therefore been set to zero.

The results in Table 5 demonstrate, as expected, that percentage differences in odour concentrations from the point source and the assumed single-house piggery become steadily smaller as distance downwind increases, with near identity beyond about 2000m. At 400m however (the Code of Practice's minimum buffer zone distance for units up to 2000 pigs) the ratio of concentrations is nearly 3, indicating the increasing importance of source dimensions as the buffer zone is reduced in size. In order to provide more general results, further calculations were made using the assumption that the pig unit had many odour sources distributed more or less uniformly over a circular area of diameter 100m. The corresponding results (column (c) of Table 5) were obtained in a similar way to those in column (b) except that the sub-sources, while still distributed uniformly acrosswind, now had magnitudes proportional to the length of the alongwind chord of the circular area on which they lay, and were represented as points on the chord centres. In this third case the Code of Practice says that the buffer zone has now to be measured from the edge of the circular unit, increasing the sampling distance by 50m over the earlier cases: it is seen that concentrations are now reduced by a further factor of nearly 3 at the shortest buffer zone distance (corresponding to 450m from the centre of the unit), but that differences from point source and single-building cases are small beyond about 2000m.

The results are obviously sensitive to the exact sizes chosen for assumed mixing heights in the building wakes, and for the crosswind dimension of building or complete unit: for example, increasing the wake mixing height to 8m would reduce

concentrations at 400m and 2000m (columns (b) and (c)) by 13% and 4% respectively; increasing the diameter of the circular unit to 200m produces concentrations lower by 50% and 39% at these two distances, but only 12% and 3% smaller at 5000 and 10000m.

Interpretation of the Code of Practice's buffer zones in the light of Table 5 is not straightforward. Use of the results in column (a) (point source) is probably not realistic usually, since in most cases mixing in building wakes will significantly broaden the source. Focussing then on those values in columns (b) and (c) and considering a range of sizes of pig units, the odour concentrations at the zone edges for urban boundaries and isolated farmhouses are given in Table 6: an odour source strength of 1 "unit" per pig per second has been assumed, with the two sets of figures under (c) referring to sites with diameter 100m(C1) and 200m (C2). Considering the buffer zone for an urban boundary,

Table 6 Comparison of estimated odour concentrations at buffer zone boundaries for different herd sizes

Head size	Statutory urban boundary				Farmhouse			
	Buffer zone size (m)	Concentration (units/m^3)			Buffer zone size (m)	Concentration		
		(b)	(C1)	(C2)		(b)	(C1)	(C2)
500	2000	.20	.16	.09	400	1.3	.50	.25
2000	2000	.80	.64	.38	400	5.4	2.0	1.0
5000	5000	.50	.47	.41	1000	5.5	2.9	1.5
10000	5000	1.0	.94	.83	1000	11	5.9	3.1

there are only fairly small differences of concentration between odours from a dispersed site (diameter 100m) and from a single house. On this basis there seems to be little justification for the arbitrary lower zone size of 2000m for all herds of less than 2000 pigs. Thus, referring back to Table 5, and making the assumptions that a 500 pig unit could involve a single pighouse, whereas a 2000 pig herd might be dispersed over a 100m circle (postulations more likely to favour the Code of Practice), the buffer zone for the smaller unit should be around 1000m instead of the 2000m laid down. The Code of Practice therefore seems to be biassed against the smaller producer.

The unit diameter is likely to increase roughly as the square root of the herd size, and so comparisons of odour concentrations for increasing herd size should be performed along diagonal lines sloping down from left to right in Table 6. No exact correspondence of buffer zone size and herd size is found, but the differences are not large enough to justify further comments for herds between 2000 and 5000 pigs. However, when the herd becomes very large (say 20000), occupying around four times the area of a 5000 pig unit, it is seen that odours from the larger unit will be several times the larger at the zone boundary, even though the source is more dispersed. The Code of Practice appears therefore to favour the very large unit.

In the case of the smallest of the buffer zones (for farmhouses), odours from individual pig houses, rather than from the whole site, become more important. Here odours from a single house with say 500 pigs would be only a few tens of percent less than from 2000 pigs over a dispersed site, for the zone distance of 400m, so the idea of using a minimum zone size for herds below 2000 pigs

becomes more tenable. For very large units (~ 20000 pigs), following the reasoning in the previous paragraph, the Code of Practice still appears to favour these units, although somewhat less so than in the context of buffer zones for adjacent urban areas. The Code's buffer zones for units between 2000 and 5000 pigs are in general mutually consistent.

The Code suggests that in regions with strongly prevailing winds the buffer zones should be reduced somewhat in size on the upwind size, but elongated substantially on the downwind size of the unit. There is no meteorological justification for this procedure, which merely allows an increase in the acceptable magnitude of odour when experienced less frequently, and a decrease if it occurs more frequently. A rather similar approach is used by the Code for topographically constrained winds, ie up or down valley, with in this case elongation of the buffer zone in both directions: however, a constrained wind is described here as $\geq$ 6 kts, a speed sufficient to dilute the odour significantly, and reduce atmospheric stability to at most class E, in either case justifying a reduction in zone size, so that again a meteorological justification for this part of the Code cannot be provided.

Two other adjustments made in the Code for variable buffer zones deserve some comment. The first reduces all buffer zones by 5% if only ridge ventilation of the buildings is used: however the advantage of this is likely to be largely modified by wake mixing, and in any case the residual advantage would be steadily eroded as mixing height of the odour increased with distance of travel. A further reduction of 5% in zone size is allowed if trees of at least 10m height surround the piggery. In the cases studied in this memorandum this would lead to an increase in virtual source distance, from around 300m to 700m if trees caused wake mixing over a height of 12m, or to 540m for wake mixing over 10m height. Table 7 shows how the upper and lower buffer zone

Table 7 Buffer zone dimensions for various wake-mixing heights

Wake mixing height (m)	Buffer zone size (m)			
	(b)	(C1)	(b)	(C1)
6	400	400	5000	5000
10	150	130	4900	4900
12	*	*	4850	4850

* zone coincides with piggery boundary

dimensions would then have to change to allow the same odour concentrations at the zone boundaries as before. These results again confirm that the results of wake mixing decline with increasing distance, and demonstrate how badly in error a single buffer zone reduction factor may be when it is applied over a wide range of zone sizes.

3. Fixed-size buffer zones

These are laid down for either effluent treatment systems or effluent disposal to land: the two most stringent categories in either case are given in Table 8. The ground areas involved for effluent treatment are likely to be roughly proportional to herd size. However, it is not clear that this would be the case

for effluent disposal to land: here the loading per unit area would be roughly independent of herd size, but the frequency of spreading might be higher for the larger unit so that at any one time the amount of recently-spread slurry might be similar for both unit sizes. Even if this last is true, the Code is still inconsistent because, as discussed earlier, it increased variable buffer zone size (for the piggery itself) on the downwind prevailing wind side to allow for a higher odour frequency in that direction.

The "worst case" analysis will treat the odour emissions as proportional to the amount of slurry produced, by assigning a ground area for treatment or disposal which is proportional to herd size. This might not be very realistic for slurry spreading, where the freshly spread material may produce a higher odour level, unless the rate of spreading is proportional to the number of animals: in this last case, spreading will be completed within the same period, regardless of herd size, and odour emission will be proportional to animal numbers.

Many other factors will control the odour levels from slurry spreading, including for example the number of small airborne particles produced during emission from the spreader, and the age and water content of the material: the Code of Practice's distinction between categories 1 and 2 in the sense of size of buffer zones are clearly arbitrary, albeit in the right direction. Similar comments apply to odours from the different types of effluent treatment systems.

The meteorological factors causing the highest odour concentrations downwind from treatment plants and spread slurry less clear at than in the case of odour emissions from pig houses. For example, the total output of odour may now increase to some extent with windspeed, so that concentration dilution by wind may be small or even negligible. Other factors such as temperature and humidity may also be important. However, since a worst case has to be assumed in testing the postulated buffer zone sizes, it will be assumed that conditions used earlier for odour emissions from piggeries (low wind speed, class F stability) will apply here also. On these bases the results in Table 9 are found. These show odour concentrations at category 1 and 2 buffer zone boundaries

Table 8 Dimensions of fixed buffer zones

	Distance (m)	
	category 1	category 2
Statutory urban boundary	2000	1500
Farmhouse	500	400

Category 1: either (a) Sludge drying beds, or drying lagoons
or (b) (i) Effluents discharged or projected to a height of at least 2m.
(ii) Liquid effluents visibly wet on ground for at least 1 hr.
(iii) Separated solids on ground surface for at least 24 hours (ie not immediately ploughed in).

Category 2: either (a) Anaerobic lagoons
or (b) Mechanical spreaders (in combination with "ploughing-in" type equipment) and downward discharge nozzles: discharge not to be projected to a height above 2m.

Table 9 "Worst case" odour concentrations downwind from effluent treatment or slurry-spreading areas

Odour* Source	Herd size involved	Odour concentrations at buffer zone boundary			
		Category 1		Category 2	
		zone size = 2000m	500m	1500m	400m
Point	100	.045	.49	.073	.72
	500	.23	2.4	.37	3.6
	2000	.90	9.8	1.5	14
	10000	4.5	49	7.3	72
50m diameter	100	.041	.23	.058	.28
	500	.20	1.1	.29	1.4
	2000	.82	4.6	1.2	5.6
	10000	4.1	23	5.8	28
100m diameter	100	.034	.12	.047	.14
	500	.17	.60	.23	.70
	2000	.68	2.4	.94	2.8
	10000	3.4	12	4.7	14
200m diameter	100	.022	.056	.027	.065
	500	.11	.28	.13	.33
	2000	.44	1.1	.54	1.3
	10000	2.2	5.6	2.7	6.5
400m diameter	100	.011	.025	.013	.028
	500	.055	.13	.065	.14
	2000	.22	.50	.26	.58
	10000	1.1	2.5	1.3	2.8

Note: * A source strength of 1 "unit" per pig per second is assumed.

for urban areas and isolated farmhouses: the figures are given for a variety of source areas, with a range of herd sizes used for each source size, allowing a rough test using the worst case hypothesis of herd size and source area being directly related; for example, if a 100 pig unit used a 50m diameter area for spreading or treatment, a 2000 pig unit would use a slightly larger than 200m diameter area.

The tabulations show that, even allowing for the source area to increase with amount of material, there is a 10-fold increase in odour concentration at the larger-size zone boundary (for urban areas), for a 20-fold increase in herd size: the corresponding increase in concentration at the buffer zone boundary for farmhouses is 4-fold. Thus, the idea of a buffer zone size for effluent treatment or disposal which is independent of herd size appears to be untenable unless either the lagoons increase in depth in proportion to the amount of slurry (very unlikely) or frequency of slurry spreading, rather than area spread on each occasion, is related to herd size: this last would lead to more frequent odours, if not to higher concentrations.

4. Conclusions

The dimensions of the Code of Practice's buffer zones do not stand up to close scrutiny. In particular, the variable buffer zone sizes laid down in the Code appear to favour the larger pig unit, and the concept of fixed zones for slurry treatment or disposal conflicts strongly with the probable variation of off-site odour concentration in relation to the size of pig unit involved.

No attempt has been made here to assess how realistic are the general sizes of the buffer zones in relation to acceptable odour for the various categories of local habitation: however, the calculations of downwind odour concentration made for arbitrary source strengths in this Memorandum provide a basis for defining buffer zones when source strengths can be estimated in individual cases.

Any comments or suggestions on this paper should be referred to the author.

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References

Health Commission of Victoria 1982 Draft Code of Practice for Piggeries.

Hosker, R. P. 1974 Estimates of dry deposition and plume depletion over forests and grasslands. In: Proc. Symposium on Physical Behaviour of Radioactive Contaminants in the Atmosphere, Vienna, Nov 1973. Vienna, IAEA, 290.

Smith, F. B. and Hay, J. S. 1961 The expansion of clusters of particles in the atmosphere. Quart. J. Royal Met Soc., 87, 82-101.

Thompson, N. and D'Costa, R. 1983 Estimating the frequency of offensive odours in the vicinity of livestock enterprises: a case-study for Norfolk. Agricultural Memorandum No. 973.